REMARKS

Favorable consideration of this application, as presently amended, is respectfully requested.

Claims 1 and 5-32 are presently active in this case. The present amendment amends Claim 1, cancels Claims 2-4, and adds new Claim 32.

New Claim 32 finds support in the disclosure as originally filed, for example at page 7, lines 1-2. Accordingly, new Claim 32 does not raise a question of new matter. None of the cited prior art teaches or suggests the subject matter recited in Claim 32 considered as a whole. Accordingly, new Claim 32 is believed to be patentably distinct over the cited prior art and allowable.

In the Office Action dated April 23, 2002, Claims 1-4, 7, 8, 10, 11, 17, 18, 20 and 21 were rejected under 35 U.S.C. 103(a) as being unpatentable over Tsuji et al. (U.S. Patent No. 5,471,068) in view of Takagi et al. (Design of Multi-Quantum Barrier (MQB) and Experimental Verification of MQB Effect). Claims 13-16 were rejected under 35 U.S.C. 103(a) as being unpatentable over Tsuji et al./Takagi et al. in view of Motoda et al. (U.S. Patent No. 5,737,350).

Applicant respectfully submits that the Claim 1, as amended, is patentably distinct over the cited prior art, as discussed next.

Briefly recapitulating, Applicant's invention relates to a light-receiving device which converts an incident light into an electric current with quantum-wave interference layer units having plural periods of a pair of a first layer and a second layer. The second layer has a wider band gap than said first layer. A carrier accumulation layer is disposed between adjacent two of the quantum-wave interference layer units. Each thickness of the first and the second layers is determined by multiplying by an *even* number one fourth of quantum-wave

wavelength of carriers in each of the first and the second layers and the carrier accumulation layer has a band gap narrower than that of the second layer. In other words, the thicknesses are multiples of $\lambda/2$.

Turning now to the applied prior art, the Takagi et al. publication discloses a structure wherein the thicknesses of the layers are determined by multiplying $\lambda/4$ by an *odd* number. In other words, the thicknesses are multiples of $\lambda/4$. The Takagi et al. publication fails to teach or suggest a structure with layers having thicknesses that are multiples of $\lambda/2$, as claimed by Applicant.

The Office Action dated April 23, 2002 takes the position that a voltage applied to the Takagi et al. device can be adjusted to change the wavelength λ and obtain a structure with layers having thicknesses that are multiples of $\lambda/2$.[1] Applicant strongly disagrees with this position, as discussed next with Attachments X1-2 and A-E. Attachment X1 shows a structure with barrier and well layers having thicknesses D_B and D_W equal to $\lambda_D(E_0)/4$ and $\lambda_W(E_0)/4$ respectively at an energy E_0. As suggested by the Office Action, at some other energy E_1, the carriers in the barrier layers can have a wavelength $\lambda_B(E_1)$ such that $D_B = \lambda_B(E_1)/2$. The question now is: what is the wavelength $\lambda_W(E_1)$ of the carriers in the *well* layers as a function of D_W? The Office Action suggests that $D_W = \lambda_W(E_1)/2$. As shown by Equations (1)-(17) of Attachment X2, however, $D_W = \frac{1}{4} \lambda_W(E_1) [(4E_0 + V) / (E_0 + V)]^{1/2}$. In other words, D_W is never equal to $\lambda_W(E_1)/2$, except when $V = 0$, which is outside the scope of the claims. The above conclusion can be reached by other means, as discussed next with the help of Attachments A-E.

The Office Action dated April 23, 2002 appears to consider that the wavelength of electrons in a barrier layer is equivalent to the wavelength of electrons in a well layer. For

[1] See outstanding Office Action, from page 3, last 5 lines to page 4, line 1.

example, at page 7, line 15, the Office Action states that "$\lambda_B = \lambda_W$." This position is incorrect. For a given energy E, one has $\lambda_B = h/(2m_BE)^{1/2}$ and $\lambda_W = h/(2m_WE + V)^{1/2}$. Because $m_B \neq m_W$ and $V \neq 0$, it follows that $\lambda_B \neq \lambda_W$.

As noted above, if one starts with a structure wherein the $D_B = \lambda_B/4$ and $D_W = \lambda_W/4$, and then adjusts the voltage so that $D_B = \lambda_B/2$, as suggested by the outstanding Office Action, the thickness for the well layer (D_W) ***will not*** be equal to a multiple of $\lambda_W/2$. Similarly, if the voltage is adjusted so that $D_W = \lambda_W/2$, the thickness for the barrier layer (D_B) ***will not*** be equal to a multiple of $\lambda_B/2$. As explained in detail below with Attachments A-E, the only structure that satisfies $D_B = \lambda_B/4$ and $D_W = \lambda_W/4$ at one voltage and satisfies $D_B = \lambda_B/2$ and $D_W = \lambda_W/2$ at another voltage is a structure where $V = 0$. Such a structure, or course, is outside the scope of the claims, which recite that one layer has a band gap wider than the other.

In the figures prepared by the Examiner and attached to the previous Office Action, the wave represented by "λ" does not show a constant wavelength. In the Examiner's figures, the thickness of the W layer is obviously different from that of the B layer. The wave shown in the Examiner's figure changes its phase by 90 degrees in the W layer and then also changes its phase by 90 degrees in B layer. In the Examiner's figures, ¼ of wavelength λ_B in the B layer and ¼ of wavelength λ_W in the W layer are shown. That is, equations "$\lambda_B / 4 = D_B$" and "$\lambda_W /4 = D_W$" are established in the Examiner's figure. Also "$D_B \neq D_W$" is established. Accordingly, "$\lambda_B \neq \lambda_W$" must be established in the Examiner's figure. If "$\lambda_B \neq \lambda_W$," the wave shown in the figure is not a sine wave. Because the wave is not a sine wave, a constant wavelength λ cannot be defined. Because "$\lambda_B \neq \lambda_W$," λ cannot be defined by λ_B and λ_W. In the equations (1) and (2) in the previously filed Attachment 1A, the relationship between λ and λ' is not clear. In that respect, Applicant does not understand what is meant by "λ' =

$\lambda/2$" from the Examiner's figures. "λ'" cannot be determined to be "$\lambda/2$" while "λ" is not defined.

The Examiner's wave is better shown by drawing an extremely thin B layer and an extremely thick W layer, as shown in Attachment A. From Attachment A, it becomes clear that "$\lambda' = \lambda/2$" has no meaning. That is, there is no wave having a constant wavelength in the multiple units of a well layer and a barrier layer.

With respect to the statements made at page 7, lines 8-13 of the Office Action dated April 23, 2002, Applicant's position is that the thickness of a barrier layer is constant: D_B. In other words, the thickness for E1 is D_B, which can be obtained from the formula (2) and determined by λ_B. Applicant agrees with the Office Action at page 7, lines 13-17 that D_B and D_W are determined by the equations (2) and (1), respectively. Applicant further agrees that D_B and D_W do not vary.

With respect to the equations in the previously filed Attachment 1A, D_B and D_W are obtained by substituting the value of E_0 for the equations (1) and (2). So, in the following equations starting from the equation (2-1), D_W, D_B, λ_W, and λ_B are fixed values. That is, thicknesses of a well layer and a barrier layer when reflection occurs, D_B and D_W, can be obtained.

Next, the Examiner shows a wave represented by λ in energy E and a wave represented by λ' in energy E' in the Examiner's figures. $\lambda_B/4$ and $\lambda_W/4$ make ½ period of the wave λ, and $\lambda'_B/2$ and $\lambda'_W/2$ make 1 period of the wave λ'.

As noted above, Applicant agrees with the Examiner that λ_W and λ_B can be obtained from the equations (2) and (1) in the previously filed Attachment 1A. In short, λ_W and λ_B can be obtained by substituting E for E_0 in the equations (2) and (1). So Applicant believes the

Examiner also agrees that λ_W' and λ_B' can be obtained by substituting E' for E_0 in the equations (2) and (1).

The point is λ_W and λ_B, obtained by the equations (2) and (1) by substituting E, and λ'_W and λ'_B, obtained by the equations (2) and (1) by substituting E', cannot satisfy the formulas $\lambda_B' = \lambda_B/2$ and $\lambda_W' = \lambda_W/2$.

Attachment B provides a more detailed explanation of this point. The wavelength conditions shown in the Examiner's figures are satisfied only when the equation (18) in the attached paper B is established. As obvious from the equations (11) and (12), the equation (18) is established only when V=0. In short, the wavelength conditions the Examiner suggests are established only when a well layer and a barrier layer are made by the equivalent materials and $m_W = m_B$. Then, $\lambda_W = \lambda_B$ is also satisfied.

Accordingly, a wave with a phase synchronized in the well layer and the barrier layer is not formed at multiple energies.

Attachment C helps to comprehend previously filed Attachment 1A and 1B more clearly. Equations (1) and (2) in attachment C are the same equations previously used in previous Office Actions. In equation (2-1) of attachment C, the energy having a wavelength λ_B/m in a barrier layer is merely replaced with E_1. Similarly, in equation (1-1), the energy having a wavelength λ_W/m in a barrier layer is merely replaced with E_2.

Equations (4) through (8) are self-explanatory. Equation (8) shows that a common energy, which makes the wavelength λ_W and λ_B of a well layer and a barrier layer at energy E_0 to be its 1/m multiple, does not exist. Accordingly, the energy which satisfies $\lambda_B' = \lambda_B/2$ and $\lambda_W' = \lambda_W/2$ as shown in the Examiner's figures never exists. Attachment C generalizes and explains that point.

As shown in Attachments D and E, in-phase wave is generated in the thicknesses of a well layer and a barrier layer only at one energy: E_0.

In view of the above, the cited prior art fails to teach or suggest every feature recited in Applicant's claims, so that Claims 1, 5-31 are believed to be patentably distinct over the cited prior art. Accordingly, Applicant respectfully traverses, and requests reconsideration of, the rejections based on the Takagi et al. publication.[2]

Consequently, in view of the present amendment, no further issues are believed to be outstanding in the present application, and the present application is believed to be in condition for formal Allowance. A Notice of Allowance for Claims 1, 5-32 is earnestly solicited.

Should the Examiner deem that any further action is necessary to place this application in even better form for allowance, the Examiner is encouraged to contact Applicant's undersigned representative at the below listed telephone number.

Respectfully submitted,

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[2] See MPEP 2131: "A claim is anticipated only if each and every element as set forth in the claim is found, either expressly or inherently described, in a single prior art reference," (Citations omitted) (emphasis added). See also MPEP 2143.03: "All words in a claim must be considered in judging the patentability of that claim against the prior art."

9438-0014-2

Marked-Up Copy
Serial No: 09/461,756
Amendment Filed on: 11-1-02

IN THE CLAIMS

Please cancel Claims 2-4 without prejudice.

Please amend Claim 1 as follows:

--1. (Amended) A light-receiving device which converts an incident light into an electric current, comprising:

quantum-wave interference layer units having plural periods of a pair of a first layer and a second layer, said second layer having a wider band gap than said first layer; and

a carrier accumulation layer disposed between adjacent two of said quantum-wave interference layer units; [and]

wherein each thickness of said first and said second layers is determined by multiplying by an even number one fourth of quantum-wave wavelength of carriers in each of said first and said second layers and said carrier accumulation layer has a band gap narrower than that of said second layer;

wherein a kinetic energy of said carriers which determines said quantum-wave wavelength is set at a level near the bottom of a conduction band and a valence band of said second layer, according to the case that said carriers are electrons and holes, respectively; and

wherein a quantum-wave wavelength λ_W in said first layer is determined by a formula $\lambda_W = h/[2m_W (E+V)]^{1/2}$, a quantum-wave wavelength λ_B in said second layer is determined by a formula $\lambda_B = h/(2m_B E)^{1/2}$, said thickness of said first layer D_W is determined by a formula $D_W = n_W \lambda_W/4$, and said thickness of said second layer D_B is determined by a formula $D_B =$

$n_B\lambda_B/4$, where h, m_W, m_B, E, V, and n_W and n_B represent Plank's constant, an effective mass of said carrier in said first layer, an effective mass of said carrier in said second layer, a kinetic energy of carriers flowing into said second layer, a potential energy of said second layer to said first layer, and even numbers, respectively. --

Please add new Claim 32 as follows:

--32. (New) A light-receiving device according to Claim 1, wherein $E \leq V/9$.--

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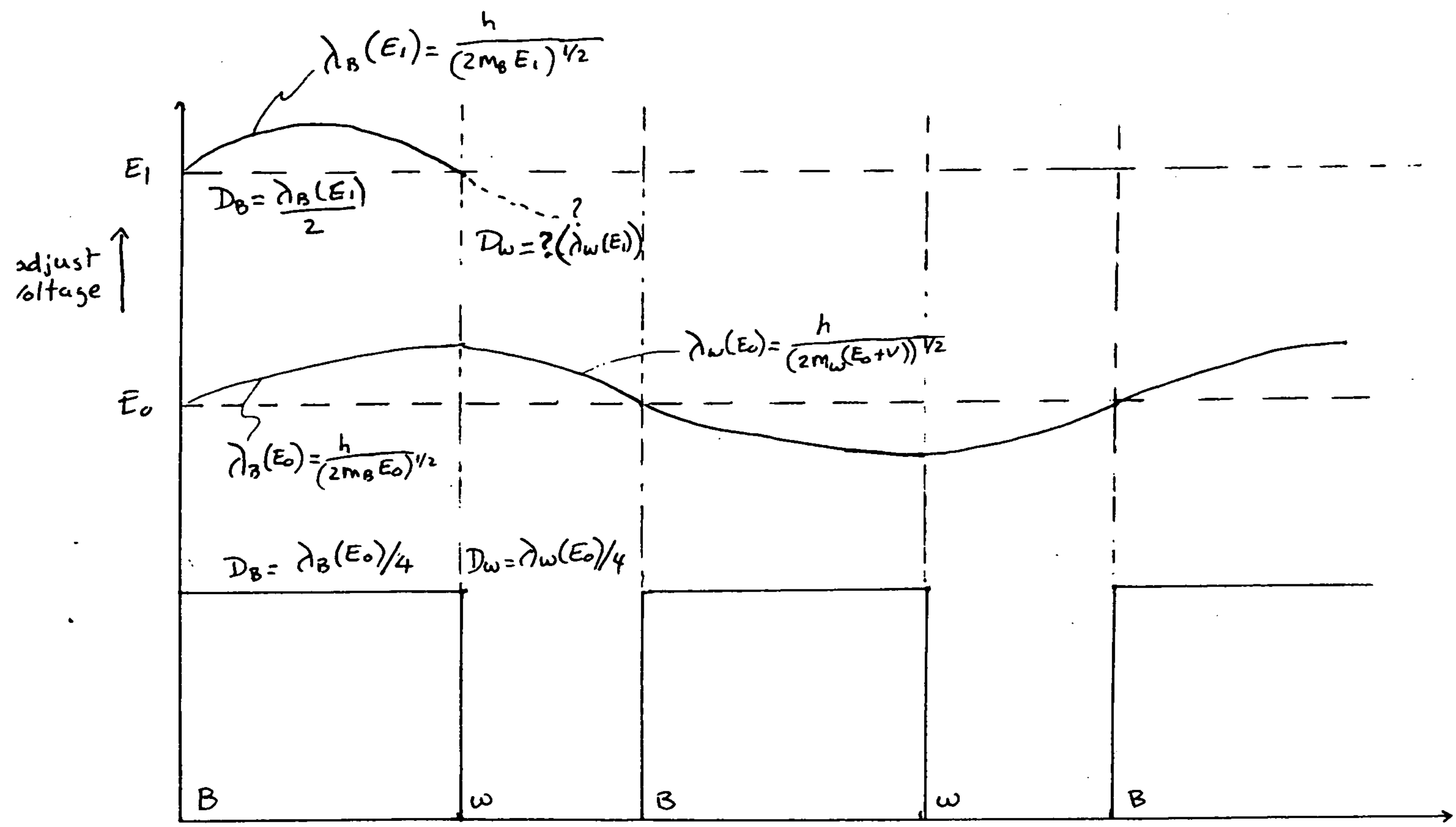
ATTACHMENT X1
09/461,756



Basic physics tells us:

(1) $\lambda_B(E_0) = \dfrac{h}{(2m_B\ E_0)^{1/2}}$; (2) $\lambda_w(E_0) = \dfrac{h}{[2m_w(E_0+V)]^{1/2}}$

(3) $\lambda_B(E_1) = \dfrac{h}{(2m_B E_1)^{1/2}}$; (4) $\lambda_w(E_1) = \dfrac{h}{[2m_w(E_1+V)]^{1/2}}$

our initial conditions are:

(5) $D_B = \lambda_B(E_0)/4$; (6) $D_w = \lambda_w(E_0)/4$

(7) $D_B = \lambda_B(E_1)/2$

our goal is to find whether:

$$D_w = \lambda_w(E_1)/2\ ?$$

ATTACHMENT X2
09/461,756

$$(1) + (5) \Longrightarrow D_B = \frac{h}{4(2m_B E_0)^{1/2}} \quad \cdots\cdots \quad (8)$$

$$(3) + (7) \Longrightarrow D_B = \frac{h}{2(2m_B E_1)^{1/2}} \quad \cdots\cdots \quad (9)$$

$$(8) + (9) \Longrightarrow \frac{h}{4(2m_B E_0)^{1/2}} = \frac{h}{2(2m_B E_1)^{1/2}} \quad \cdots\cdots \quad (10)$$

$$(10) \Longrightarrow E_1 = 4E_0 \quad \cdots\cdots \quad (11)$$

$$(11) + (4) \Longrightarrow \lambda_w(E_1) = \frac{h}{\left[2m_w(4E_0+V)\right]^{1/2}} \quad \cdots\cdots \quad (12)$$

multiply (12) by $\frac{\sqrt{\frac{E_0+V}{4E_0+V}}}{\sqrt{\frac{E_0+V}{4E_0+V}}} = 1 \Rightarrow \lambda_w(E_1) = \frac{h\sqrt{\frac{E_0+V}{4E_0+V}}}{\left[2m_w(4E_0+V)\right]^{1/2}\left(\frac{E_0+V}{4E_0+V}\right)^{1/2}}$

$$\Downarrow$$

$$\lambda_w(E_1) = \frac{h\sqrt{\frac{E_0+V}{4E_0+V}}}{2m_w(E_0+V)^{1/2}} \quad \cdots\cdots \quad (13)$$

$$(2) + (13) \Longrightarrow \lambda_w(E_1) = \lambda_w(E_0)\sqrt{\frac{E_0+V}{4E_0+V}} \quad \cdots\cdots \quad (14)$$

$$(6) + (14) \Longrightarrow \lambda_w(E_1) = 4D_w\sqrt{\frac{E_0+V}{4E_0+V}} \quad \cdots\cdots \quad (15)$$

$$\Downarrow$$

$$D_w = \frac{\lambda_w(E_1)}{4}\sqrt{\frac{4E_0+V}{E_0+V}} \quad \cdots\cdots \quad (16)$$

$$D_w \neq \frac{\lambda_w(E_1)}{2} \quad \cdots\cdots \quad (17)$$

unless $V=0$

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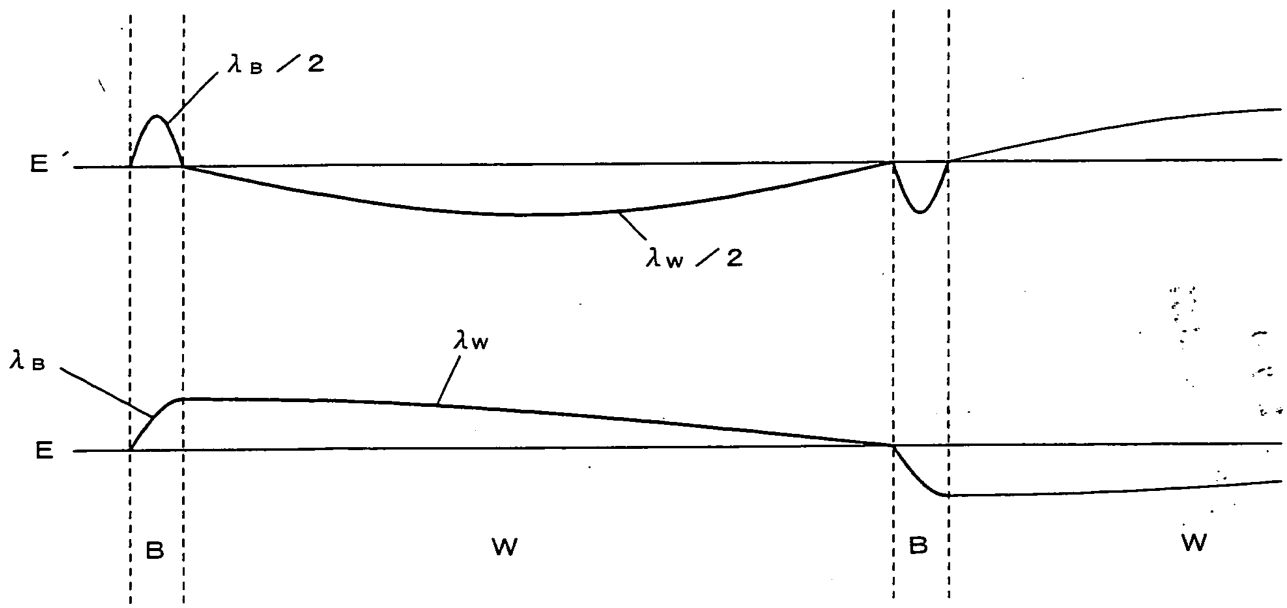
ATTACHMENT A
09/461,756



ATTACHMENT B
09/461,756

λ_W and λ_B are decided by E

$$\lambda_W = \frac{h}{\sqrt{2m_W(E+V)}} \quad \cdots (11)$$

$$\lambda_B = \frac{h}{\sqrt{2m_B E}} \quad \cdots (12)$$

λ_W' and λ_B' are decided by E'

$$\lambda_W' = \frac{h}{\sqrt{2m_W(E'+V)}} \quad \cdots (13)$$

$$\lambda_B' = \frac{h}{\sqrt{2m_B E'}} \quad \cdots (14)$$

We get Eq. (15) eliminating E from Eqs. (11) and (12).

$$V = \frac{h^2}{2}\left(\frac{1}{m_W\lambda_W^2} - \frac{1}{m_B\lambda_B^2}\right) \quad \cdots (15)$$

We get Eq. (16) eliminating E from Eqs. (13) and (14).

$$V = \frac{h^2}{2}\left(\frac{1}{m_W\lambda_W'^2} - \frac{1}{m_B\lambda_B'^2}\right) \quad \cdots (16)$$

from Eqs. (15) and (16)

$$\frac{1}{m_W\lambda_W^2} - \frac{1}{m_B\lambda_B^2} = \frac{1}{m_W\lambda_W'^2} - \frac{1}{m_B\lambda_B'^2} \quad \cdots (17)$$

If $\lambda_B' = \lambda_B/2$, $\lambda_W' = \lambda_W/2$ as shown in the examiner's drowing, we get the following Eq.

$$\frac{\lambda_B}{\lambda_W} = \sqrt{\frac{m_W}{m_B}} \quad \cdots (18)$$

λ_W and λ_B are decided by E_0

$$\lambda_W = \frac{h}{\sqrt{2m_W(E_0 + V)}} \quad \cdots (1)$$

$$\lambda_B = \frac{h}{\sqrt{2m_B E_0}} \quad \cdots (2)$$

E_1 which is corresponding to $\frac{\lambda_B}{m}$ is obtained as follows.

$$\frac{\lambda_B}{m} = \frac{h}{\sqrt{2m_B E_1}} \quad \cdots (2-1)$$

Here m is integer $\geqq 2$.

from Eq. (2−1).

$$E_1 = \frac{h^2 m^2}{2m_B \lambda_B^2} \quad \cdots (3)$$

E_2 which is corresponding to $\frac{\lambda_W}{m}$ is obtained as follows.

$$\frac{\lambda_W}{m} = \frac{h}{\sqrt{2m_W(E_2 + V)}} \quad \cdots (1-1)$$

from Eq. (1−1).

$$E_2 = \frac{h^2 m^2}{2m_W \lambda_W^2} - V \quad \cdots (4)$$

We get Eq. (5) eliminating E_0 from Eqs. (1) and (2).

$$V = \frac{h^2}{2}\left(\frac{1}{m_W \lambda_W^2} - \frac{1}{m_B \lambda_B^2}\right) \quad \cdots (5)$$

Accordingly Eq. (6) is obtained from Eqs. (4), (3), (5).

$$E_2 - E_1 = \frac{h^2(m^2-1)}{2}\left(\frac{1}{m_W \lambda_W^2} - \frac{1}{m_B \lambda_B^2}\right) \quad \cdots (6)$$

Substituting $\left(\frac{1}{m_W \lambda_W^2} - \frac{1}{m_B \lambda_B^2}\right)$ of Eq. 5 into Eq. (6), we get Eq. (7)

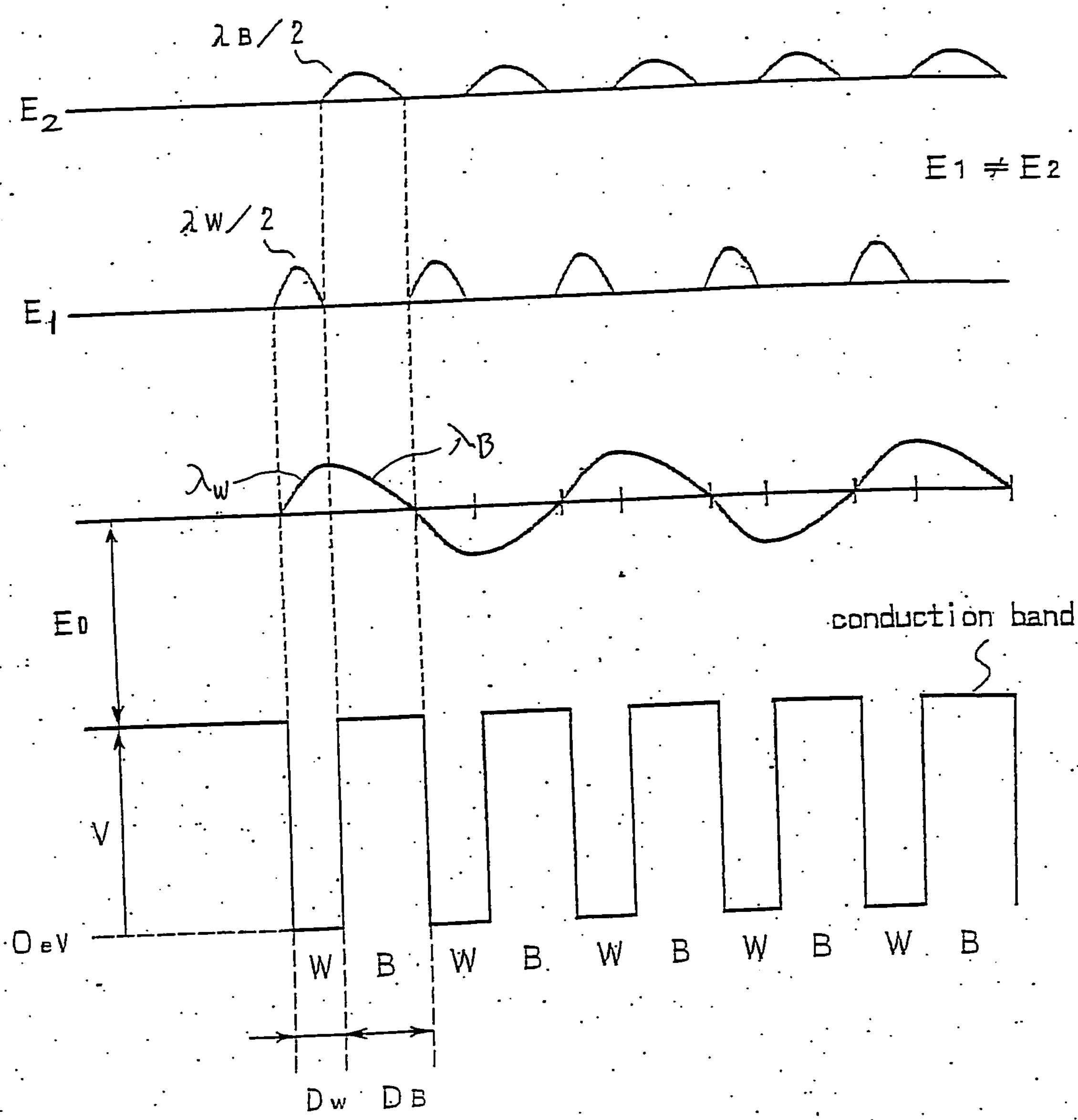
$$E_2 - E_1 = (m^2-1)V \quad \cdots (7)$$

As a result,

$$E_2 \neq E_1. \quad \cdots (8)$$

ATTACHMENT D
09/461,756

Design for Reflection



ATTACHMENT E
09/461,756

Design for transmission